CHAPTER 6

# Groundwater Recharge

The Stormwater Management Regulations has two options to address the groundwater recharge requirement. The first option is to maintain 100 percent of the existing annual groundwater recharge volume. The second option – to infiltrate the increase in the two-year storm – can be addressed through standard hydrologic and hydraulic analyses. However, the methodology to demonstrate that the existing groundwater recharge volume is maintained is not addressed by the standard stormwater computations.

The attached User Guide and spreadsheet allows the evaluation of the existing groundwater recharge, proposed groundwater recharge and the change in annual recharge resulting from development. It also assists with determining the size and location of a structure to demonstrate that 100 percent of the annual groundwater recharge volume is maintained.

# The NJ Groundwater Recharge Spreadsheet

## A Brief User Guide

There are three computational worksheets in the spreadsheet:

1. **Annual Recharge Worksheet:** This worksheet which resides on the first page of the spreadsheet is used to estimate the annual groundwater recharge volumes that occur naturally under the existing and proposed conditions. Based on a value of "*% of Existing Annual Recharge to Preserve*" that the user provides, the worksheet calculates "*The Required Annual Recharge Volume*" in cubic feet. This is the annual recharge volume deficit that must be provided by one or more BMPs or LID-IMPs.

2. **BMP-Calculations:** This worksheet which resides on the second page of the spreadsheet is used to design the required size and configuration of one or more infiltration BMP or LID-IMPs to satisfy "*The Required Annual Recharge Volume*" calculated in the Annual Recharge Worksheet.

*Worksheets in the NJ Groundwater Recharge Spreadsheet other than the first three pages are either data sheets or graphs of the results neither of which should be changed by the user.*

## Procedure to Use the Annual Recharge Worksheet

Figure 1 is a screen capture from an example application of the Annual Recharge Worksheet.

**Annual Groundwater Recharge Analysis (based on GSR-32)**

| Select Township ↓ | Average Annual P (in) | Climatic Factor |
|---|---|---|
| MIDDLESEX CO., MONROE TWP | 45.2 | 1.45 |

**Existing Conditions**

| Land Segment | Area (acres) | LULC | Soil | Annual Recharge (in) | Annual Recharge (cu.ft) |
|---|---|---|---|---|---|
| 1 | 1.4 | landscape open space | Woodstown | 11.6 | 59,017 |
| 2 | 0.3 | unvegetated | Woodstown | 6.3 | 6,854 |
| 3 | 3.5 | wooded - general | Woodstown | 12.0 | 152,136 |
| 4 | 1.4 | landscape open space | Keyport | 12.3 | 62,531 |
| 5 | 0.3 | unvegetated | Keyport | 7.0 | 7,630 |
| 6 | 3.5 | wooded - general | Keyport | 12.5 | 159,098 |
| 7 | 0 | | | - | - |
| 8 | 0 | | | - | - |
| 9 | 0 | | | - | - |
| 10 | 0 | | | - | - |
| Total = | 10.4 | | | Total Annual Recharge (in) | Total Annual Recharge (cu-ft) |
| | | | | 11.8 | 447,266 |

**Proposed Conditions**

| Land Segment | Area (acres) | LULC | Soil | Annual Recharge (in) | Annual Recharge (cu.ft) |
|---|---|---|---|---|---|
| 1 | 1.5 | unlandscaped developed | Keyport | 0.0 | - |
| 2 | 1.6 | unlandscaped developed | Woodstown | 0.0 | - |
| 3 | 3.65 | landscape open space | Keyport | 12.3 | 163,028 |
| 4 | 3.65 | landscape open space | Woodstown | 11.6 | 153,866 |
| 5 | 0 | | | - | - |
| 6 | 0 | | | - | - |
| 7 | 0 | | | - | - |
| 8 | 0 | | | - | - |
| 9 | 0 | | | - | - |
| 10 | 0 | | | - | - |
| Total = | 10.4 | | | Total Annual Recharge (in) | Total Annual Recharge (cu.ft) |
| | | | | 8.4 | 316,895 |

**Annual Recharge Requirements Calculation**

| | |
|---|---|
| % of Existing Annual Recharge to Preserve = | 100% |
| The Required Annual Recharge Volume (cu.ft) = | 130,371 |

Procedure to fill the Existing Conditions and Proposed Conditions Tables

For each land segment, first enter the area, then select LULC, then select Soil. Start from the top of table

**Figure 1. Screen Capture Showing the Annual Recharge Worksheet.**

*All user-input cells are in tan color. All cells in gray are used to show calculation results (or internal validity checks) and must not be changed by the user.*

As the first step, you must select the project township. Click once on the township cell and select your township from the drop-down list (Combo Box) of all NJ townships arranged by counties in alphabetical order. Once you select the township, the values of average annual precipitation and the climate factor are set for the given township in the two cells to the immediate right of the township name.

The next step is for you to provide information about existing (pre-development) conditions. The first column is the land segment number. Up to ten different land segments can be inputted in this table.

*If you have more than ten different land segments try to lump similar segments together or subdivide your area into smaller areas not consisting of more than ten land segments.*

For each land segment, first enter the area, then select Land use/Land Cover (LULC), then select Soil. Start from the top of table and proceed downward. Don't leave blank rows (with A= 0) in between your segment entries. Rows with zero areas will not be displayed or used in calculations. To select the appropriate LULC and Soil click once on each cell and select from the choices in the Combo Box.

*Once you click on any of these cells a pop-up help message will appear to briefly tell you about the required input for that cell.*

Impervious areas that are part of the standard residential lots are accounted for by selecting the appropriate choice from the Combo Box (e.g. ".5 to 1 acre lots"). All other impervious areas could be lumped together and selected as "unlandscaped developed" from the Combo Box for the LULC. In the existing conditions table soil type for impervious areas are irrelevant and do not show up and the recharge for these areas is set at zero. Typically, there are no residential lots or developed LULCs in the existing conditions.

Once you are done inputting all land segment information in the table for the existing conditions check the total area (below the area column) to make sure that the total project area is correct. The last two columns of this table show the naturally occurring average annual recharge values (depth in inches and volume in cubic feet) for each land segment. Below the recharge depth column the average depth of recharge over the entire area is given. Below the recharge columns the total annual recharge volume (in cubic feet) over the total area under existing conditions is given. This number is used in calculation of recharge deficit.

The above procedure can be used to fill-in the required data for the proposed conditions. However, normally there will be one or more land segments that must be set at one of the choices of residential development. The impervious area outside of standard lots are set as "unlandscaped developed" from the Combo Box. The soil type for such land segment will be initially hidden just like in the proposed condition table. However, if an infiltration facility is proposed to be built within these areas, the soil type is no longer irrelevant and the user is required to select the soil underlying the impervious area from the Combo Box. In this case, the impervious land segment or segments that might host an infiltration facility must be inputted in a separate land segment line than the rest of the impervious areas.

*Soils selected for the impervious areas in the proposed conditions table are automatically displayed in orange color signifying that they have no effect on annual recharge calculation (set to zero for all land segments classified as "unlandscaped developed" regardless of the soil type) but that they can affect the annual recharge calculation for an infiltration capacity placed within the impervious area.*

Once you are done inputting all land segment information in the table for the proposed conditions check the total area (below the area column) to make sure that the total project area is correct. *If the total area in the proposed conditions is different from the total area in the existing conditions a warning message will appear to the right of the value for the total are of the proposed conditions.*

Also, as an additional check, the total impervious area (in square feet) is shown to the bottom right of this table (not shown in Figure 1). Notice that this value does not include the impervious areas within the standard residential lots.

The last two columns of this table show the naturally occurring average annual recharge values (depth in inches and volume in cubic feet) for each land segment. Below the recharge depth column the average depth of recharge over the entire area is given. Below the recharge column the total annual recharge volume (in cubic feet) over the total area under proposed conditions is given.

Immediately below the proposed conditions table you can see the table of Annual Recharge Requirements Calculation. You need to input the "% of Existing Annual Recharge to Preserve" to set the percentage of the annual recharge volume under existing conditions that must be maintained under the proposed conditions. Normally this value is set to 100%.

*Consult NJDEP for the appropriate value of "% of Existing Annual Recharge to Preserve" for your area.*

The spreadsheet then finds the difference between the total annual recharge volumes of the proposed versus the existing conditions and multiplies it by the "% of Existing Annual Recharge to Preserve". The resulting value shown as "The Required Annual Recharge Volume" in this worksheet (130,371 cubic feet in case of the example in Figure 1) is the volume of groundwater recharge in cubic feet that must be artificially provided in the proposed conditions through infiltration BMPs or LID-IMPs.

The table under annual recharge table shows the Recharge Efficiency parameters Calculations. These parameters are calculated in this worksheet but are used in the other worksheets of this spreadsheet.

*Appendix A gives the Basic Equations and defines the Variables used in Recharge Efficiency Parameters Calculations.*

## Procedure to Use the BMP-Calculations Worksheet

This worksheet allows the proper sizing of infiltration BMPs (or LID-IMPs) to provide the desired volume of annual recharge. Alternatively it can be used to evaluate the performance of a recharge facility of given size. You can either find the size of one facility to satisfy the entire recharge deficit calculated from the Annual Recharge worksheet or analyze the performance of a smaller facility by changing the values of design parameters.

Figure 2 is a Screen capture from part of the BMP-Calculations Worksheet. Most of the calculations in this worksheet are performed in rows 22 to 100, not shown in Figure 2. To understand the worksheet usage you need to focus on the main input/output part of the worksheet shown in Figure 2. There are ten sections and three solve buttons on this part of the worksheet as explained below.

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Infiltration BMP Input Parameters | | | | Root Zone Water capacity Calculated Parameters | | | | Recharge Design Parameters | | | |
| 2 | Parameter | Symbol | Value | Unit | Parameter | Symbol | Value | Unit | Parameter | Symbol | Value | Unit |
| 3 | BMP Area | ABMP | 5,028 | sq.ft | Empty Portion of RWC under Post-D Natural Recharge | ERWC | 1.08 | in | Inches of Runoff to capture | Qdesign | 0.22 | in |
| 4 | BMP Effective Depth | dBMP | 6.0 | in | ERWC Modified to consider dEXC | EDRWC | 1.08 | in | Inches of Rainfall to capture | Pdesign | 0.39 | in |
| 5 | BMP below ground depth must be<=dBMP | dEXC | 0.0 | in | Empty Portion of RWC under Infilt. BMP | RERWC | 0.85 | in | Recharge Provided Avg. over Imp. Area | | 11.6 | in |
| 6 | Proposed Conditions Land Segment Location of BMP , Input Zero if Location is distributed or undetermined | SegBMP | 0 | unitless | | | | | Runoff Captured Avg. over imp. Area | | 14.1 | in |
| 7 | Solve for ABMP to provide Vdef | Solve for dBMP to provide Vdef | | Default Vdef & Aimp | BMP Calculated Size Parameters | | | | | | | |
| 8 | | | | | ABMP/Aimp | Aratio | 0.04 | unitless | | CALCULATION CHECK ME | | |
| 9 | | | | | BMP Volume | VBMP | 2,514 | cu.ft | Volume Balance-> | OK | | |
| 10 | Parameters from Annual Recharge Worksheet | | | | System Performance Calculated Parameters | | | | dEXC Check---> | OK | | |
| 11 | Post-D Deficit Recharge (or desired recharge volume) | Vdef | 130,371 | cu.ft | Annual BMP Recharge Volume | | 130,371 | cu.ft | BMP Location---> | Location is selected as dis | | |
| 12 | Post-D Impervious Area (or target Impervious Area) | Aimp | 135,036 | sq.ft | Avg BMP Recharge Efficiency | | 82.3% | Represents % Infiltration Recharged | | Notes | | |
| 13 | Root Zone Water Capacity | RWC | 3.94 | in | %Rainfall became Runoff | | 77.8% | % | Pdesign is accurate only after BMP dimensions are updated to mak | | | |
| 14 | RWC Modified to consider dEXC | DRWC | 3.94 | in | %Runoff Infiltrated | | 40.1% | % | The portion of BMP infiltration prior to filling and the area occupic | | | |
| 15 | Climatic Factor | C-factor | 1.45 | no units | %Runoff Recharged | | 32.9% | % | Results are sensetive to dBMP, designer must make sure dBMP s | | | |
| 16 | Average Annual P | Pavg | 45.2 | in | %Rainfall Recharged | | 25.6% | % | For Land Segment Location of BMP if you select "unlandscaped D | | | |
| 17 | Recharge Requirement over Imp. Area | dr | 11.6 | in | | | | | | | | |

**Figure 2. Screen Capture from the BMP-Calculations Worksheet.**

## Infiltration BMP Input Parameters

You can start by inputting an initial value for the BMP surface area, ABMP in square feet. If you are analyzing a given recharge facility this value is fixed, otherwise this value is only your initial guess for the size of the required facility to satisfy a desired volume of annual recharge as set by the parameter Vdef (see cell C11 in Figure 2).

Next, you need to enter a value for the facility effective depth dBMP in inches. Just like ABMP, this is either a given value or your initial guess. Notice that the effective depth corresponds to the maximum depth of infiltration that the device can deliver during one complete filling.

If bottom of the recharge facility is below the ground surface you need to input the value of dEXC in inches to represent the portion of the facility depth that lies below surface. Otherwise, leave this value at zero. For example, if a 36-inch deep infiltration trench is completely excavated below the ground level and is filled with gravel with a void ratio of 0.33, then the effective BMP depth dBMP would be 12 inches (36 x 0.33) and dEXC would be 36 inches.

As can be seen under parameters from Annual Recharge Worksheet, by default the spreadsheet assigns the values of total deficit recharge volume "Vdef" and total proposed impervious area "Aimp" from the "Annual Recharge" sheet to "Vdef" and "Aimp" on this page. This allows solution for a single BMP to handle the entire recharge requirement assuming the runoff from entire impervious area is available to the BMP.

To solve for a smaller BMP or a LID-IMP to recharge only part of the recharge requirement, set Vdef to your target value and Aimp to impervious area directly connected to your infiltration facility and then solve for ABMP or dBMP. To retrieve the default configuration click the "Default Vdef & Aimp" button.

*Notice that the default configuration assumes that the runoff from the entire impervious areas set by selecting one or more segments to "unlandscaped developed" (and not impervious areas within the standard residential lots) is available to divert into the BMP .*

*In this worksheet user-input cells are in tan color. All cells in gray are used to show calculation results and must not be changed by the user. The only exceptions to this rule are the cells for ABMP and dBMP that can be altered from their default values by the user. Default values for these cells can be restored by clicking on the "Default Vdef & Aimp" button.*

The last input cell is the segBMP parameter which represents "Proposed Conditions Land Segment Location of BMP". For example, if the BMP (or LID-IMP) is proposed to be built in the Land Segment 3 from the proposed conditions tables of Figure 1, then enter 3 for segBMP. Input Zero if the location of the BMP is still undetermined or a series of LID-IMPs will be used that will be distributed over two or more land segments.

Once all input values are provided the user can click on either of the two solve buttons to solve the problem. If you click on the "Solve for ABMP to provide Vdef" then the program adjusts the value of ABMP while keeping dBMP constant so that the average annual recharge volume of the system would equal Vdef. If you click on the "Solve for dBMP to provide Vdef" then the program adjusts the value of dBMP while keeping ABMP constant so that the average annual recharge volume of the system would equal Vdef. If you used the default Vdef value the system will be sized to satisfy the entire recharge deficit. If you change the Vdef before clicking either of these buttons then the system will be sized to provide the target recharge volume set by you.

*If the initial guess values you enter for ABMP or dBMP are drastically off from what is needed to satisfy Vdef (i.e. too small or too big or too shallow or too deep) then the program may not be able to find the right answer. You can tell the answers are not acceptable because negative values or division by zero signs will show up. If this happens just change your ABMP and/or dBMP values to more realistic numbers and solve the problem again.*

The values shown in Figure 2 are the final results obtained by solving for ABMP (with a constant dBMP of 6 inches) to satisfy the entire annual recharge deficit of 130,371 cubic feet (the default value). You can tell the results are correct by checking the value calculated for "Annual BMP Recharge Volume" under the "System Performance Calculated Parameters" section.

## Parameters from Annual Recharge Worksheet

This section contains various parameters read from the annual recharge worksheet. You may change the values of Vdef and Aimp and retrieve the default values as explained above. The values for Root Zone Water Capacity, and RWC Modified to consider dEXC are automatically adjusted to reflect your choices for the location of the BMP and the below-surface portion of the BMP. Climatic Factor, and Average Annual P values are constant values for the township selected at the top of the Annual Recharge worksheet. If you like to use this worksheet for a different township you would have to go back to the first page and change the township there.

*Warning: by changing the township you also change the annual recharge deficit.*

The last row in this section gives "Recharge Requirement over Imp. Area", dr. This is the average depth of annual recharge over the inputted impervious area (either default or target area). This number is calculated by dividing Vdef by Aimp.

The next section of the worksheet is a help message to explain how to solve for different recharge volumes.

## Root Zone Water Capacity Calculated Parameters

This section contains the calculated results for three root zone water capacity parameters. These values are needed for estimating the recharge efficiency of the facility. They enable the estimation of the portion of the infiltrated water that travels below the root zone which is equivalent to recharging the local groundwater resources according to assumptions set by NJ DEP. These values are automatically adjusted for project location, land segment in which the BMP is to be located (or area weighted average if segBMP is set to zero).

*See Appendix A for more information about these parameters.*

## BMP Calculated Size Parameters

This section contains the values for two auxiliary design parameters: ABMP/Aimp is the ratio of the BMP surface area to the impervious surface area that runs off to the BMP, and BMP Volume is the volume of the facility in cubic feet.

## System Performance Calculated Parameters

The values in this section give the main system performance criteria. The first value, "Annual BMP Recharge Volume", is the most important output. This value must match Vdef for the facility to completely satisfy the annual recharge deficit or the target recharge volume as described previously.

The next parameter, "Avg BMP Recharge Efficiency", gives the percentage of infiltrated water that travels below the root zone over an average year. The value of this variable depend on many factors including the project location, land use/land cover, soil types, BMP dimensions, excavated depth of BMP, etc. For the example in Figure 2 the recharge efficiency is just over 82%.

The rest of the performance parameters in this section are self-explanatory from the spreadsheet.

## Recharge Design Parameters

The first value in this section is "Inches of Runoff to capture" which gives the minimum depth of runoff over the impervious area that must be controlled and diverted to the BMP to allow the system to satisfy the specified recharge deficit.

The next parameter "Inches of Rainfall to capture" gives the minimum depth of rainfall over the impervious area that must be controlled and diverted to the BMP to allow the system to satisfy the specified recharge deficit. This value is the project-specific design rainfall for groundwater recharge. The conversion of rainfall to runoff over the impervious area is calculated using a three-level approach; for $P < 0.0408$ inches $Q = 0$, for $0.0408 < P < 1.25$" $Q=0.855*(P-.0408)$, for $P>1.25$ " Q is calculated by SCS with CN=98.

The next parameter in this section "Recharge Provided Avg. over Imp. Area" must match the value of “dr” introduced previously for the system to satisfy Vdef.

The last parameter in this section "Runoff Captured Avg. over imp. Area" is the total depth of runoff over the impervious area that is controlled and diverted to the BMP and actually infiltrates. It does not contain the part of runoff from the impervious area that is diverted to the BMP but spills over the BMP capacity during large events.

## CALCULATION CHECK MESSAGES

In this section the worksheet provides three messages to check the validity and finality of the results. The first line is a check of volume balances. If the problem is solved successfully, the message in this section would say “OK”. However, if the resulting recharge volume does not match Vdef, the user is instructed to solve the problem. This may happen if you change any of the design parameters and forget to solve the problem by clicking on any of the two solve buttons.

The next line checks the value you inputted for dEXC. If this value is larger than the dBMP, a warning message is issued telling you to make dEXC smaller than dBMP. Notice that in rare occasions the facility may be buried deeper underground than its overall depth. In such cases, just ignore the warning message of this section. The recharge efficiency of deep recharge facilities approaches 100% since only minor losses due to lateral flow to layers above the root zone are possible.

The last line in this section is a check of the location of the BMP inputted by the user. If the user has entered a valid segment number for segBMP, the message will read as “OK”. If the user enters a zero for segBMP then the message will read “Location is selected as distributed or undetermined”. However, if the user enters a land segment number that was not previously defined in the Annual Recharge worksheet under proposed conditions then the message will say: "Land Segment Number Selected for BMP is not Defined".

## Notes

This section contains a few notes on the assumptions and limitations of the calculations in this worksheet. In the current version of the spreadsheet, these notes read as follows:

- Pdesign is accurate only after BMP dimensions are updated to make rech volume= deficit volume
- The portion of BMP infiltration prior to filling and the area occupied by BMP are ignored in these calculations.
- Results are sensitive to dBMP, designer must make sure dBMP selected is small enough for BMP to empty in less than 3 days.
- For Land Segment Location of BMP if you select "unlandscaped Developed" RWC will be minimal but not zero as determined by the soil type and a shallow root zone for this LULC. This allows consideration of lateral flow and other losses.

# Appendix A

## Basic Equations and Variables Used in Recharge Efficiency Parameters Calculations

Basic Equations for Soil Water capacity

**A. Equation from GSR-32:**

RWC = Root Depth x AWC (1)

RWC: Root zone Water Capacity, (inch)
AWC: Available Water Capacity, (inch/ft)

**B. New Equation:**

ERWC = (1-0.5 x C-Factor) x RWC (2)

ERWC: Empty Root Zone Water Capacity under natural recharge, (inch)
C-Factor: Climate Factor = Ratio of precipitation to potential ET, (unit less)
Range of Values in NJ: RWC: (0.3, 14.35), C-Factor: (1.18-1.83)
ERWC: (0.02, 5.88)

Infiltration and Artificial Recharge under BMP or LID-IMP

$$\text{Average Annual Total Infiltration Depth} = \sum_{i=1}^{n} \text{Minimum (Qi/Aratio, dBMP)} \qquad (3)$$

n = total number of runoff producing precipitation events on an average year.
Aratio = Ratio of surface area of BMP (ABMP) to the impervious surface area served by the BMP (Aimp), unit less.

Find Average Empty RWC under Infiltration Facility

**A. Modification to account for the buried portion of the facility**

DRWC = Maximum (Root Depth – 0.5 x dexc) x AWC (4)

DRWC = Root zone water capacity under BMP modified for the buried portion of the BMP and calculated over all land segments, (inch)

**B. Define the empty portion of EDRWC**

EDRWC = (1- 0.5 x C-Factor) x DRWC (5)

EDRWC = Empty Portion of DRWC, (inch)

**C. Account for the effect of moisture supplied by infiltration facility in reduction of empty portion of root zone**

$$\text{REavg} = (1/n) \sum_{i=1}^{n} \text{Maximum (EDRWC - infi)} \qquad (6)$$

REavg = DRWC modified to account for infiltration under BMP, (inch)
infi = Infiltration depth in BMP during "i"th event (inch)

RERWC = (n/365) x REavg + [(365-n)/n] x EDRWC (7)

RERWC = Average empty root zone water capacity under BMP operation calculated for the average RWC of all land segments (inch)

$$\text{RBMP} = \sum_{i=1}^{n} \text{Maximum (infi – RERWC, 0)} \qquad (8)$$

RBMP = Total infiltration depth under BMP during an average year, (inch)

$$\text{BMP Recharge Efficiency} = \frac{\text{RBMP}}{\sum_{i=1}^{n} \text{infi}} \qquad (9)$$

In equations (8) and (9), results are very sensitive to C-Factor. As C-Factor increases, natural recharge increases and recharge deficit due to development increases. Our equations imply that if you are blocking recharge in an area of high natural recharge, your artificial recharge efficiency under BMP would also be high, so the size of recharge facility required would not be unduly big in areas with large C-Factor.

The above parameters are calculated in the spreadsheet for each land segment as well as for the entire area (area weighted average) under proposed conditions. If the user specifies the location of the recharge BMP/LID-IMP or then the relevant parameters of the same land segment will be used. If the user does not specify the location, then the area average values will be used.